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"Stability Criterion of a Processing Plant using PID Controller"

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ABSTRACT

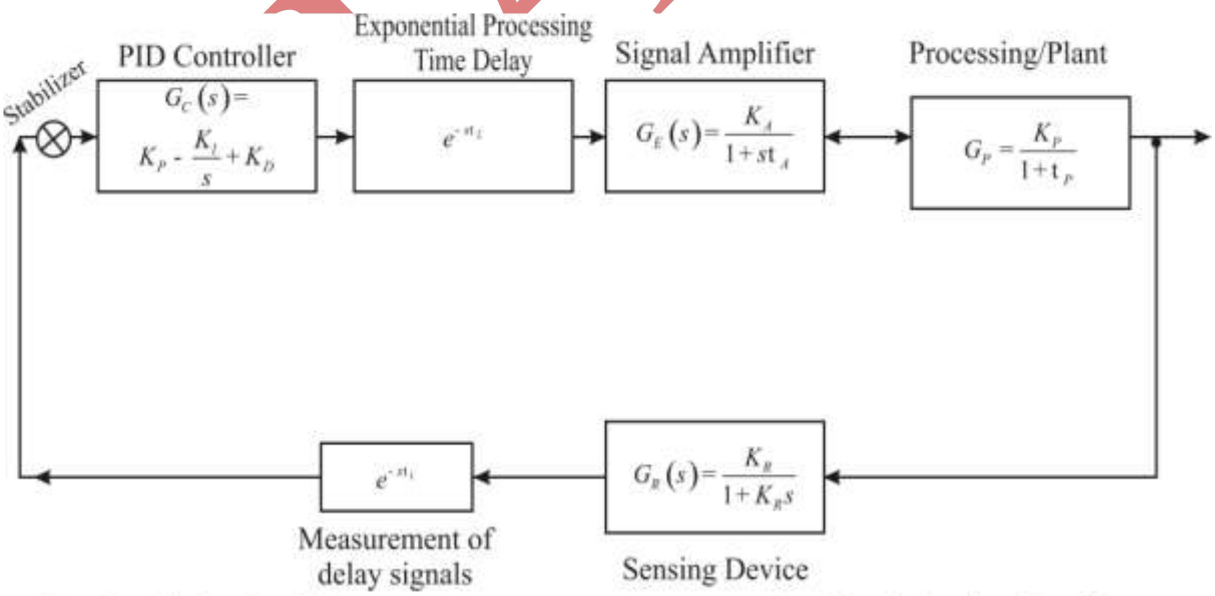
This paper presents an stability criterion of an unstable Processing Plant using PID Controller. The effect of time delay plays an important and significant role for considering of the stability of Processing having generator and excitation control system and it's associated with other measuring devices, communication links used for data transfer. The time delay also called as delay margin is determined ideally by using PID controller. Under some specified condition of time delay, the processing plant having excitation loses and their stability. Therefore, to make the system stable, an stabilizer is used to generate the processing signals for the specified time in order to damper the low frequency oscillations for the time delay and PID controller with stabilizer. It performs the better operation of the processing.

Key Words: *Process Plant, Time delays, Delay margin, PID controller with Stabilizer.*

I. INTRODUCTION

In any process control system. It is necessary to maintain the control parameters by maintaining the voltage magnitude and frequency within the specified limit. The processing control system of plant behaves like an excitation control system which regulates the reactive power and voltage magnitude of a synchronous generator at same specified level during steady state period and reduce voltage level gradually during required and specified period affecting on stability.

In process plant systems, it is necessary to maintain the voltage magnitude and frequency within the specified limits. The processing control system also known as automatic voltage regulator (AVR) regulates the reactive power and voltage magnitude of a synchronous generator at a specified level. The processing AVR quality influences the voltage level during steady state operation, and also reduces the voltage oscillations during transient state periods, affecting the overall system stability. The controllers are used to set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits. This paper investigates the effect of the time delay on the stability of the generator excitation control system. The use of measurement devices and communication networks for data transfer, there is a possibility to exist significant time delays.



G_p = Transfer function of plant, G_a = Transfer function of amplifier,

Gs = Transfer function of sensing device, G_c = Transfer function of PID controller

Figure 1: Block Diagram of Processing Plant with Time Delay

Depending on the communication link is used, to analysis the communication delays is considered to be in the range of 80-600 milliseconds. In power system control, the total measurement of delay is taken in the order of several milliseconds. Therefore, the total measurement and communication delays involved between the instant of measurement and that of signal being available to the controller the major problem in the control system of ten arises. This delay can typically be in the range of 0.5-1.0 seconds. These time delays in power system have a destabilizing impact on the system dynamics which leads to loss of synchronism and instability. Therefore, there is a need to know the maximum amount of time delay known as delay margin of AVR system that the system can tolerate without losing its stability. Low-frequency oscillations have a common problem in large control system. A control system stabilizer can provide an supplementary control signal to the excitation system of the power generating unit to damp these oscillations. So, the conventional control system stabilizer is widely used in existing power systems and has contributes to the enhancement of the dynamic stability of control systems.

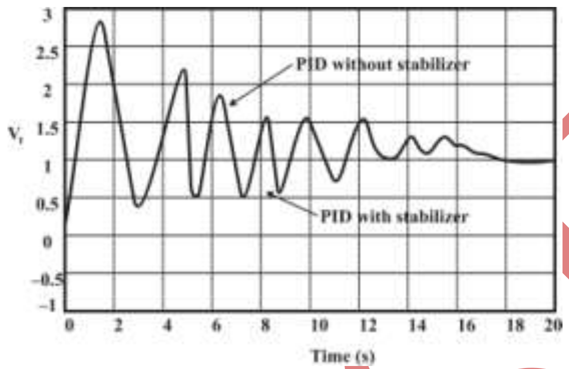


Fig.2: Voltage Response 'Vt' for K_p=1.0, K_I=0.2$_s^{-1}$, K_D=0.05s and τ=0.16s.

II. MODELLING OF CONTROL SYSTEM WITH TIME DELAYS

Modelling of processing plant, with time delay, a generalised model is commonly used to design a controller activity. Figure shows the block diagram of processing plant with time delays. Each component of the system is modeled by a first-order transfer function and their terms are having usual meanings. The PID controller is used to improve the dynamic response as well as to reduce the steady state error during process. The PID controller having transfer function is

$$G_C(s) = K_P + \frac{K_I}{s} + K_{D^s} \quad (1)$$

Where K_P, K_I and K_D are the proportional integral and derivative gains. The measurement of delaying signal. τ_1 and processing delay τ_2 are the respective time delays, which are expressed in exponential terms. The effect of PID controller will give the response of excitation system for the desired performance. The characteristic equation of the processing control system can be obtained.

$$l + G_C(s)G_A(s)G_B(s)G_G(s)G_R(s)e^{-s(\tau_1+\tau_2)} = 0 \quad (2)$$

as $$\Delta(s,\tau) = P(s) + Q(s)e^{-x\tau} = 0 \quad (3)$$

where $\tau=\tau_1+\tau_2$. The polynomials *P(s)* and *Q(s)* are having the coefficients in terms of time constants of the system are given in Appendix A.

$$P(s) = s(1+T_A s)(1+T_E s)(1+T_G s)(1+T_R s)$$

$$= T_5 s^5 + T_4 s^4 + T_3 s^3 + T_2 s^2 + s \quad (4)$$

$$Q(s) = \left(K_P s + K_I + K_D s^2\right) K_A K_E K_G K_R$$

In the following section, a formula is to be compute for delay margin for a stable operation of the processing control system is presented.

III. STABILITY CRITERIAN

A. Identification Problem

The stability criterion for two classes of time-delay systems for processing plant.

(i) *Delay-independent stability:* Holds for all positive values of the delay.

(ii) *Delay-dependent stability:* Asymptotic stability holds for some values of the delay ($\tau<\tau^*$) and the system is violated for other values of delay $\tau>t^*$ then the system becomes unstable.

Note, that the delay-free system (τ=0) is assumed to be stable.

The problem can be stated as follows arises in processing plant using various controller.

Determine: If it is delay-independent stable or not; if not (the time-delay system is delay-dependent stable).

Find: The delay-margin τ^* that keeps the system stable.

In the following section, an analytical formula is derived to compute the delay margin for the delay-dependent is presented.

B. Solution Method

An control system is said to be asymptotically stable, all the roots of lie in the left half of the complex plane. If for some τ, $\Delta(s, \tau) = 0$ has a root on the imaginary axis at $s=j\omega$, so does $\Delta(-s, \tau) = 0$ for the same value of τ and ω. Hence, looking for roots on the imaginary axis reduces to finding values of τ for which $\Delta(s, \tau) = 0$ and $\Delta(-s, \tau) = 0$ have common root. That is

$$P(s)P(-s)e^{-x\tau} = 0$$

$$P(-s)+Q(-s)e^{x\tau} = 0 \qquad (5)$$

By eliminating exponential terms in above equation, we get the following polynomial:

$$P(-s)+P(-s)-Q(s)Q(-s) = 0 \qquad (6)$$

If we replace s by jw in (6), we have the following polynomial in $W(\omega^2)$:

$$W(\omega^2) = P(j\omega)P(-j\omega)-Q(j\omega)Q(-j\omega) = 0 \qquad (7)$$

Substituting *P(s)* and *Q(s)* polynomials given in (4) into (7), we obtain

$$W(\omega^2) = p_{10}\omega^{10} + p_8\omega^8 + p_6\omega^6 + p_4\omega^4 + p_2\omega^2 + p_0 = 0 \quad (8)$$

where the coefficient p_0, p_2, p_4, p_6, p_8 and p_{10} are real valued and are given in Appendix VI.

If we denote the roots of (8) with respect to ω^2 by r_k, then $\omega_k = \pm\sqrt{r_k}$, so that for real value of ω_k, the value of r_k must be positive. If there is no positive root of)8) with respect to ω^2, that is all $r_k<0$, the system is stable for all $\tau \geq 0$, which indicates that the system is delay-independent stable. If there exist the positive roots of the polynomial (8) with respect to ω^2, then the system is delay-dependent stable. The value of τ can be obtained as follows:

$$\Delta(j\omega_k, \tau) = P(j\omega_k)+Q(j\omega_k)e^{-j\omega_k\tau} = 0$$

$$e^{-j\omega_k\tau} = \cos(\omega_k\tau) - j\sin(\omega_k\tau) = \frac{P(j\omega_k)}{Q(j\omega_k)} \qquad \cos(\omega_k\tau) = \mathrm{Re}\left[\frac{P(j\omega_k)}{Q(j\omega_k)}\right]$$

and $$\sin(\omega_k\tau) = \mathrm{Im}\left[\frac{P(j\omega_k)}{Q(j\omega_k)}\right] \tag{9}$$

From (9), we can determine an analytical formula for the upper bound of the time delay τ^* as follows:

$$\tau^*_{k,r} = \frac{\theta}{\omega_k} + \frac{2r\pi}{\omega_k}; \quad r = 0,1,2....,\infty \tag{10}$$

where $$\theta = \tan^{-1}\left(\frac{\mathrm{Im}\left\{\frac{P(j\omega_k)}{Q(j\omega_k)}\right\}}{\mathrm{Re}\left\{\frac{P(j\omega_k)}{Q(j\omega_k)}\right\}}\right)$$

It must be stated here that inverse tangent operation always gives angles in the right half-plane. For this reason, the angle θ is in the range $[-\pi/2, \pi/2]$. However, θ must be in the left half-plane when $\cos(\omega_k\tau) < 0$. Therefore, π must be added to or subtracted from the angle θ when $\cos(\omega_k\tau) < 0$ to correct delay margin results $\tau^*_{k,r}$ as follows:

$$\tau^*_{k,r} = \frac{\theta}{\omega_k} + \frac{2r\pi}{\omega_k}; \quad r = 0,1,2....,\infty \tag{11}$$

where $$\theta = \left(\frac{q_7\omega_k^7 + q_5\omega_k^5 + q_3\omega_k^3 + q_1\omega_k}{q_6\omega_k^6 + q_3\omega_k^3 + q_2\omega_k^2}\right)$$

where the coefficients $q_1, q_2, q_3, q_4, q_5, q_6$ and q_7 are real valued and are given in Appendix A. Please note that π must be added to or subtracted from the angle θ when $q_6\omega_k^6 + q_4\omega_k^4 + q_2\omega_k^2 < 0$ to correct delay margin results $\tau^*_{k,r}$ in (11). for each $\omega_k^2; k = 1,2.....q$ we can get infinitely many $\tau^*_{k,r}$, values by using (11). According to the definition of delay margin, the minimum of $\tau^*_{k,r}, k = 1,2....,q$ is the system delay margin.

$$\tau^* = \min\left(\tau^*_{1,1}, \tau^*_{2,1}, ..., \tau^*_{q,1},\right) \tag{12}$$

IV. THEORETICAL RESULTS

The delay margin τ^* is calculated for a certain values of PID controller gains, the gain and time constants of the excitation system used are given in the following Table (1).

For the theoretical analysis, the gain and time constants of the exciter control system used are as follows [11, 12]: K_A=5, K_E–K_G=K_R=1.0 and T_A=0.1 seconds, T_E=0.4 seconds, T_G=1.0 seconds, T_R=0.05 seconds. Substitute the above values and the PID controller gain values, we can easily compute the delay margin τ^* using the expression given by (12) are given in table (1). The theoretical results are verified by using time-domain.

Table 1

Theoretical Values of Delay Margin

K_P	$K_I(s^1)$	$K_D(s)$	*Delay Margin*
0.3	0.8	0.15	2.0035
0.5	0.6	0.1	1.6315
0.7	0.5	0.05	0.8775
0.9	0.3	0.1	0.44
1.1	0.1	0.05	0.125

V. CONCLUSION

In this paper, the stability of processing plant is analyzed in the presence of time delays. A delay margin is computed for the delay dependent case and the computed delay margins are verified using time domain simulations of Matlab/Simulink for various processing plant. A comparison is also made for stability using certain PID without stabilizer and PID with stabilizer by a simulink model. In the future Fuzzy Logic Controller will also be used instead of conventional PID controller. Thus stability criterion has been derived and applied for various processing plant, where nos of control variables are involved.

VI. APPENDIX

The coefficients of the polynomial *P(s)* given in (4):

$$T_5=T_AT_PT_R$$

$$T_4=T_AT_PT_R+T_AT_P+T_PT_R+T_AT_PT_R$$

$$T_3=T_AT_E+T_P+T_ET_R+T_AT_R+T_AT_P$$

$$T_2=T_A+T_E+T_P+T_R$$

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